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Effects of synthetic explanatory variable on saturation magnetization of colloidal nanomagnetite slurry

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ABSTRACT

In this contribution, stable nanomagnetite slurry have been successfully prepared by coprecipitation method. The synthesis parameters, such as reaction temperature, heating time, surfactant concentration and precipitating agent addition rate affected magnetic properties of synthetic nanomagnetite slurries were also investigated. We discovered the optimum reaction parameters based on the highest saturation magnetization obtained under our experimental condition to disperse magnetite nanoparticles in the aqueous medium using dodecanoic acid as a surfactant. The highest saturation magnetization was achieved when 0.5:1 mole ratio of dodecanoic acid to magnetite was used and NH_4OH with an addition rate of 5 ml min^{-1} was added to the solution while time and temperature for heating were 45 min at 80 °C.

Introduction

Magnetite nanoparticle (MNPs) is the most commonly used iron oxide nanoparticles possessing superparamagnetic property and biocompatibility [1]. Superparamagnetic iron oxide nanoparticles have been extensively investigated in recent years for diverse applications including biomedical such as drug delivery [2,3], magnetic resonance imaging (MRI) contrast agent [4,5], cell separation [6] and etc. Furthermore, there are plentiful reports on the application of MNPs as nano agents in water treatments through removal of heavy metals [7], organic pollution [8], colorants [9], and suspended solids [10].

Furthermore, colloidal form of iron oxide nanoparticles or so-called iron oxide slurry is of great interest and widespread importance due to its rich behavior and extensive application in multidisciplinary fields of science and technology. Moreover, the efficacy of many applications highly depends on characteristics of aqueous colloidal suspension of iron oxide

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nanoparticles, including well-dispersibility and narrow size distribution of nanoparticles [1]. For instance, super-paramagnetic colloidal suspension containing nanoparticles in aqueous medium enhances the nuclear magnetic relaxation of water protons and makes advancement in the contrast in MRI [11].

The colloidal suspension of iron oxide nanoparticles must remain single phase (liquid) even in the presence of the drastic magnetic field. From this point of view, the capability of iron oxide slurry to react towards a magnetic field as well as its fluidity have been brought it very unique properties and wide range of applications [12]. However, different experimental tests on the stability of the synthesized slurries have revealed their tendency to aggregate. Iron oxide nanopaticles are prone to form a cluster because of the intensive magnetic dipole–dipole interaction between their particles [13]. Therefore, surface modification of nanoparticles in order to supply a repulsive electrostatic force is inevitable. The enormous amount of surfactants has been used to provide steric stability for nanoparticles to be suspended in the aqueous medium. It is highly recommended that chosen surfactant contains a functional group to interact with the iron oxide particles and form firmly bonded-monomolecular layer surrounding the particles [14]. Despite the fact that surface modification of iron oxide nanoparticles is strongly required to overcome magnetic interactions and to enhance the stability of the particles in the medium, coating layer on the nanoparticle's surface dramatically reduces the magnetic properties [15].

Various techniques have been widely applied to synthesize iron oxide nanoparticles [16]. Coprecipitation method as a straightforward, cost effective and reproducible technique is the frequently used method to synthesize iron oxide nanoparticles, which affords better purity and homogeneity in the compounds in comparison with other methods [17]. Since synthetic methods may need specific conditions, in the case of coprecipitation technique also some parameters need to be governed in order to obtain fine product possessing desired properties. These factors may be considered as the concentration of the solution, reaction temperature, pH, mixture stirring speed and etc [18]. It has to be taken into account that the main disadvantage of the coprecipitation method is the difficulty to control the reaction parameters. Otherwise, it can result in undesirable particle size and size distribution. Additionally, the formation of different phases of iron oxide can simply take place. Therefore, some studies have investigated the main factors which possibly impacting the fabrication of magnetic nanoparticles such as initial pH [19] and pH of the solution [20], iron salt concentration [21] and temperature [18,20,21]. However, they mostly focused on quality and performance of MNPs on the suspension and its stability. Moreover, some have particularly centralized on structure and surface properties of functionalized magnetic iron oxide nanoparticles. Here, we have investigated synthetic key parameters affecting exclusively the magnetic properties of the whole slurry (colloidal suspension) such as surfactant concentration, precipitating agent addition rate, reaction temperature and heating time.

Experimental procedure

Materials

Ferrous chloride tetrahydrate ($FeCl_2.4H_2O$), ferric chloride hexahydrate ($FeCl_3.6H_2O$), ammonia solution (28% NH_4OH), Dodecanoic acid ($C_{12}H_{24}O_2$, 99%) were all purchased from Sigma–Aldrich Co., (USA). All the chemicals and solvents were used without further purification. Moreover, during the experiments, Millipure water with a resistivity of greater than 18.0 MΩ/cm was used.

Preparation of iron oxide slurry using different concentrations of surfactants

In a typical method, a solution of 1.2 M $FeC1_2.4H_2O$ and 1.8 M $FeCl_3.6H_2O$ using deionized water were prepared and combined into a 600-ml beaker. A certain amount of ammonium hydroxide (28% NH_4OH) was added while stirring until the pH of the solution reach to 10. The beaker containing the resulting precipitate was then placed onto a permanent magnet to accelerate precipitate sedimentation. After standing on the magnet for 5 min, the clear salt solution was decanted. The precipitate was then washed by mixing with a solution containing 5 ml of ammonium hydroxide in 95 ml of water. This mixture was also placed on a permanent magnet for 5 min before decanting the clear solution. To investigate the effect of surfactant concentration, different amounts of dodecanoic acid, 0.0, 0.6, 1.5, 3.0 and 6.0 g (mole ratio of dodecanoic acid to magnetite = 0:1, 0.2:1, 0.5:1, 1:1, 2:1) was finally added to the precipitate, and the mixture heated at 80 °C for 45 min while stirring.

Preparation of iron oxide slurry using different precipitating agent addition rate

To investigate the effect of precipitating agent rate of addition on magnetic properties, we repeated the experiments exactly as explained above. The optimum point of surfactant concentration was chosen in which the highest saturation magnetization has been achieved. After mixing the solution of iron salts and stirring, a certain amount of NH_4OH was added to the solution by 1, 2, 5, 10, 20, 40 and 60 ml min^{-1} rate. The rest of procedure was followed as mentioned above.

Preparation of iron oxide slurry using different reaction temperatures

To examine the effect of reaction temperature on magnetic properties, we repeated the experiments exactly as explained above. The optimum point of surfactant concentration and precipitating agent rate of addition (NH_4OH) was chosen in which the highest saturation magnetization has been achieved. The rest of procedure was followed as mentioned above. In this case the heating temperature were chosen 25, 30, 40, 50, 60, 70, 80 and 90 °C.

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